Maximal aerobic capacity for repetitive lifting: comparison with three standard exercise testing modes

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Summary. A multi-stage repetitive lifting maximal oxygen uptake ($\dot{V}O_{2max}$) test was developed to be used as an occupational repetitive lifting research tool which would parallel standard ergometric $\dot{V}O_2max$ testing procedures. The repetitive lifting $\dot{V}O_2max$ test was administered to 18 men using an automatic repetitive lifting device. An intraclass reliability coefficient of 0.91 was obtained with data from repeated tests on seven subjects. Repetitive lifting $\dot{V}O_2max$ test responses were compared to those for treadmill, cycle ergometer and arm crank ergometer. The mean±SD repetitive lifting $\dot{V}O_{2max}$ of 3.20 ± 0.42 $l \cdot min^{-1}$ was significantly ($p<.01$) less than treadmill $\dot{V}O_2max$ (Δ=0.92 $l \cdot min^{-1}$) and cycle ergometer $\dot{V}O_{2max}$ (Δ=0.43 $l \cdot min^{-1}$) and significantly greater than arm crank ergometer $\dot{V}O_2max$ (Δ=0.63 $l \cdot min^{-1}$). Repetitive lifting $\dot{V}O_2$ and power output were linearly related for most individuals, with a median correlation coefficient of 0.98. When the repetitive lifting data for all subjects were combined, this relationship was not as strong (r=.65) due to the variation in slope between subjects. $\dot{V}O_2max$ correlated highly among exercise modes, but maximum power output did not. Economy (W/l $\dot{V}O_2$) of repetitive lifting exercise was significantly greater than that for arm cranking and less than that for leg cycling. The repetitive lifting $\dot{V}O_2max$ test has an important advantage over treadmill or cycle ergometer tests in the determination of relative repetitive lifting workloads. The individual curves of $\dot{V}O_2$ vs. power output established during the multi-stage lifting $\dot{V}O_2max$ test can be used to accurately select work loads required to elicit given percentages of maximal oxygen uptake.

Key words: Oxygen consumption - Work efficiency - Repetitive Lifting - Exercise testing - Exercise economy

Introduction

Exercise intensity is generally expressed as either a mean rate of oxygen uptake or as a percentage of an individual's maximal oxygen uptake ($\dot{V}O_2max$). The average exercise intensity recommended for an 8 hour work day is between 21 and 50% of $\dot{V}O_2max$ depending on the nature of the exercise and the mode of assessing $\dot{V}O_2max$ (Astrand 1977; Jorgensen and Poulsen 1974;Legg and Myles 1981; Petrofsky and Lind 1978b). $\dot{V}O_2max$ is commonly determined during exercise on a motor driven treadmill or cycle ergometer. The National Institute for Occupational Safety and Health guidelines (NIOSH 1981) recommends an average repetitive lifting exercise intensity of no more than 33% $\dot{V}O_2max$ for an 8 hour day, but the exercise testing mode used to determine $\dot{V}O_2max$ is not specified. Setting exercise intensity relative to treadmill or cycle ergometer $\dot{V}O_2max$ may be valid for tasks involving movement similar to running and cycling, but it may not provide a realistic description of the intensity of common work tasks such as repetitive lifting (Petrofsky and Lind 1978b; Randle and Legg 1985). The deficiency of using a non-lifting $\dot{V}O_2max$ test for setting relative lifting intensities becomes critical in an industrial research setting, where accurate determination of relative repetitive lifting intensity is needed.

Accounting for inter-individual differences in economy (power output/$\dot{V}O_2$) during task performance is important when attempting to equate exercise intensity among subjects (Cavanagh 1985). It has been demonstrated that changes in lifting technique result in a marked difference in metabolic cost at submaximal levels, due in part to changes in the quantity of muscle mass involved (Garg and Herrin 1979; Mital and Ayoub 1981; NIOSH 1981) Even the most standardized lifting technique will incorporate some intra-subject variability due to morphological differences. Therefore, differences in the economy of lifting between individuals should be examined.

Directly measured (Petrofsky and Lind 1978a) and predicted (Intaranont et al. 1986) repetitive lifting $\dot{V}O_2max$ tests have been reported. The procedures used did not always parallel standard treadmill, leg and arm cycle ergometry testing procedures. The test of Petrofsky and Lind (1978a) consisted of lifting a fixed mass a short distance at increasing frequency. Most $\dot{V}O_2max$ testing procedures involve increasing the exercise intensity by increasing treadmill grade or ergometer belt resistance, rather than by increasing speed alone (Astrand and Rodahl 1977; Mitchell et al. 1957; Sawka et al. 1983). A repetitive lifting $\dot{V}O_2max$ test at a fixed lifting rate with increases in mass lifted seems more consistent with standard ergometry techniques. The repetitive lifting $\dot{V}O_2max$ predictive tests reported by Intaranont et al. (1986) were not validated with actual $\dot{V}O_2max$ tests and were based on short, anatomically relative lifting distances. Standard lifting heights are more likely to be encountered in an industrial setting.

The purpose of this study was to develop a reliable multi-stage repetitive lifting $\dot{V}O_2max$ test to be used as a laboratory tool, which paralleled standard ergometer $\dot{V}O_2max$ testing procedures. A secondary purpose was to compare the repetitive lifting $\dot{V}O_2max$ test responses to those obtained during treadmill, cycle ergometer and arm crank ergometer tests utilizing similar testing procedures. The economy of maximal and submaximal repetitive lifting exercise was examined and compared to that of leg cycling and arm cranking.

Material and methods

Eighteen men were briefed, medically screened and gave their informed consent to participate in the study. The sum of four skinfolds (biceps, triceps, suprailiac and subscapular) was used to estimate body fat (Durnin and Womersley 1974).

All subjects performed discontinuous $\dot{V}O_2max$ tests on a repetitive lifting device (Teves et al, 1986), Quinton treadmill, Monark cycle ergometer and modified Monark arm crank ergometer (Sawka et al. 1983). One test was executed at the same time each day with 24-48 hours rest between test sessions. The testing protocols have been reported elsewhere by Mitchell et al. (1957) for treadmill, Astrand and Rodahl (1977) for cycle ergometer, and Sawka et al. (1983) for arm crank ergometer. Each test began with a 3-6 minute warm up followed by three to five additional 2.5 to 4 minute exercise bouts. Each additional bout was of increasing intensity and was separated from the previous bout by a 10 minute rest period.

$\dot{V}O_2max$ was defined as a plateau in $\dot{V}O_2$ (<0.15 $l \cdot min^{-1}$ increase in $\dot{V}O_2$ with an increase in power output). An attempt was made to reach a plateau on all tests, but during attempted maximal loads subjects were often not able to perform long enough to reach a steady state. Plateaux were obtained on all treadmill tests, 4 cycle ergometer tests, 2 arm crank ergometer tests and 7 repetitive lifting tests. When a true plateau could not be reached, the highest $\dot{V}O_2$ obtained before a subject was unable to continue indicates the maximal rate that subject could reach for that particular activity. For this reason, all tests will be referred to as maximal oxygen uptake ($\dot{V}O_2max$).

Expired gases were collected through a low resistance two way Daniels valve into vinyl Douglas bags during the last minute of each exercise level. Expired gas samples were analysed for gas fractions using Beckman LB-2 CO_2 and Applied Electrochemistry S-3A O_2 gas analysers. Gas volumes were measured using a Collins chain-compensated Tissot spirometer. Minute ventilation was corrected to BTPS and oxygen uptake to STPD. Heart rate was continuously monitored with an oscilloscope and recorded on an electrocardiograph during each $\dot{V}O_2max$ test. Disposable electrodes were placed in a CM5 configuration for

repetitive lifting and arm crank ergometer and V5 for treadmill and cycle ergometer. The CM5 configuration was used to avoid excess EMG and movement artifact during upper body exercise. Heart rate was recorded during the last 30 sec of each exercise intensity.

The repetitive lifting $\dot{V}O_2max$ test was performed with the aid of a pneumatically driven lifting/lowering device (Teves et al. 1986) modelled after the one developed by Snook and Irvine (1968). When a metal box, 47 x 23 x 31 cm in width, height and depth, respectively, with side handles was placed on the raised shelf of the device, a field proximity switch closed and the shelf was automatically lowered to floor level. When the box was removed from the shelf, the switch was opened and the shelf returned to 132 cm (approximately chest height for most males). The lifting height was the same for all individuals, because standard lifting heights are more likely to be encountered in an industrial lifting situation than anatomical lifting heights. The initial box mass was 15 kg and was increased by 2-4 kg for each successive exercise bout. Lifting exercise incorporates both the work of lifting an object and that of lifting the body. In order to prevent the box mass from becoming prohibitively heavy and still produce a high power output, the lifting rate was set at 15 $lifts \cdot min^{-1}$ (Mital and Ayoub 1981). Subjects were instructed to maintain this pace throughout each exercise bout using a freestyle lifting technique. Extensive pilot testing found this to be the fastest rate all trained subjects could maintain while lifting to 132 cm. Slower rates with greater box masses tended to produce a lower repetitive lifting $\dot{V}O_2max$. Several subjects assumed a pace slightly faster than 15 lifts/min, and all subjects were encouraged to lift the final load as rapidly as possible. Submaximal lifting was performed for 3 minutes, and the maximal load was lifted for 2.5 minutes. A timer and counter on the repetitive

lifting device allowed for an accurate assessment of exercise time and lifting rate. Each subject practiced lifting for a minimum of two weeks to allow for familiarization with the apparatus and technique.

The power required for the box lift was calculated using the following equation, which takes into account work in raising both the box and the lifter's body.

$$P = F(W_B T_B + W_L T_L)/60.0$$

where;

P = power (watts)
F = lift frequency (lifts/minute)
W_B = box weight (newtons)
T_B = vertical box travel (meters)
W_L = lifter's body weight (newtons)
T_L = vertical travel of the lifter's center of mass (meters)

Vertical box travel was taken as the vertical distance between the floor and shelf upon which the box was placed. Vertical travel of a subject's center of mass during lifting was calculated from films taken with a Locam camera (Redlake Corp, Morgan Hill, CA) at 60 frames per second. The films were projected onto the back of a translucent glass screen, and the frames where the lifter's body was highest and lowest during a lift were located. Graph paper tracings were made in which dots were drawn over the wrist, elbow, shoulder, hip, knee and ankle joints, and lines drawn between the dots to represent the major body segments. Using an anthropometric table, the center of mass of each body segment was located as a proportion of the distance between the segment ends, and marked on the tracings. The whole body vertical center of mass was calculated using the following equation (Winter 1979):

$$y_{cm} = \sum_{i=1}^{n} f_i y_i$$

where

y_{cm} = vertical coordinate of the lifter's center of mass

y_i = vertical coordinate of the i^{th} body segment

f_i = i^{th} segment's fraction of total body mass (from table)

n = number of segments in body model

The vertical travel of the lifter's center of mass was taken as the difference between the highest and lowest vertical coordinates of his center of mass during the lift. A multiplying factor derived from the tracing and measurement of an object of known size in the camera's field of view was used to obtain the vertical distance in meters of the high and low point of the body center of mass from the corresponding graph coordinates.

Maximal lift was determined using two different methods. With the first, the subject repeatedly lifted on a weight stack machine from a starting height of 20cm to a final height of 152 cm. The mass lifted was increased by 4.5 kg after each successful lift, until the subject was unable to complete the lift. A bent knee, straight back lifting technique was required. The mass range of the weight stack was 20 - 91 kg. The last successful load lifted prior to failure was accepted as the maximal machine lift.

A second determination of maximal lift was made using the repetitive lifting device with the shelf locked at 132 cm and a box similar to that used during the repetitive lifting $\dot{V}O_2max$ test. Following a warm up, mass was added to the box with each successful lift in increments between 1 and 11 kg. Approximately one minute rest was allowed between lifts, and an attempt was made to reach the subjects' maximum within 5 to 7 lifts. The last successful weight lifted was accepted as the maximal box lift. Experienced test administrators stood on either side of the subject, and assisted in lowering the box after an unsuccessful lift.

The economy of exercise (Cavanagh 1985), defined as power output divided by oxygen uptake (watts/$l \cdot min^{-1}$), was determined for each exercise bout performed on the repetitive lifting, cycle and arm crank ergometers. Absolute power output varied considerably between the three exercise modes, as did the number of submaximal exercise intensities per subject. In order to meaningfully compare economy across exercise modes the data were grouped into three exercise specific relative intensity categories. The intensity levels were moderate (60-74% power output at $\dot{V}O_2max$), high (75-90% power output at $\dot{V}O_2max$) and maximal (>91% power output at $\dot{V}O_2max$).

One way analysis of variance with a preset alpha level of .01 was used to examine the significance of differences in physiological responses across the four exercise modes. Tukey post hoc analyses were performed to isolate significant differences. Pearson's correlation coefficients were used to examine relationships between descriptive measures and repetitive lifting $\dot{V}O_2max$ test responses, as well as the correlation of physiological variables among exercise modes.

Results

Descriptive statistics for age, height, weight, body composition and maximal lifts of the subjects are listed in Table 1. An intraclass reliability coefficient of 0.91 was determined using the results of seven subjects who performed the repetitive lifting $\dot{V}O_2max$ test twice. No significant difference was found between trials in $\dot{V}O_2max$, in any of the other physiological variables, nor in the box mass at repetitive lifting $\dot{V}O_2max$.

Physiological data from the four $\dot{V}O_2max$ tests are shown in Table 2. Repetitive lifting $\dot{V}O_2max$ was significantly less than treadmill running

(Δ=0.92 $l \cdot min^{-1}$) and leg cycling $\dot{V}O_2max$ (Δ=0.43 $l \cdot min^{-1}$) and greater than arm cranking $\dot{V}O_2$ max (Δ=0.63 $l \cdot min^{-1}$). Heart rate at repetitive lifting $\dot{V}O_2max$ was significantly lower than at treadmill $\dot{V}O_2max$, but was not significantly different than at arm cranking or leg cycling $\dot{V}O_2max$. Expired minute ventilation ($\dot{V}E$) at repetitive lifting $\dot{V}O_2max$ was significantly less than $\dot{V}E$ at either treadmill or cycle ergometer $\dot{V}O_2max$. During maximal exercise, $\dot{V}E/\dot{V}O_2$ was significantly less for repetitive lifting than for cycle or arm crank ergometry. The subjects lifted an average of 41% ± 6% of their maximal box lift during the final exercise bout of the incremental repetitive lifting $\dot{V}O_2max$ test.

For each subject a plot of $\dot{V}O_2$ as a function of power output was made on a common scale for repetitive lifting, cycle ergometry and arm cranking. Several examples are illustrated in Figure 1. The repetitive lifting power output vs $\dot{V}O_2$ relationship was linear in most cases, with a median correlation coefficient of 0.98. There was a large variation in slope from subject-to-subject. The most common pattern observed (15 of 18) was one in which the cycle ergometer curve was below those of the other two exercise modes. For half of the subjects, repetitive lifting and arm crank ergometry were on the same line (examples A and B of Figure 1). Two subjects showed a linear increase over the power output range, regardless of exercise mode (example C of Figure 1). In several cases, the arm crank ergometer curve had a much steeper slope than that for either repetitive lifting or cycle ergometer (examples D-F of Figure 1). In no case was the cycle ergometer power output vs $\dot{V}O_2$ curve above those of repetitive lifting and arm crank ergometry, indicating that it is the most efficient form of exercise of the three.

Descriptive statistics for the economy of repetitive lifting, arm cranking and leg cycling are listed in Table 3. There was no significant change in the

economy of repetitive lifting or arm cranking across exercise intensity levels. Cycle ergometer exercise became increasingly more economical as the intensity level increased. All exercise modes were significantly different from each other at each intensity level. Repetitive lifting was consistently less economical than cycle ergometry and more economical than arm crank exercise.

The correlations between physiological responses to maximal repetitive lifting exercise and responses to maximal treadmill, arm crank and cycle ergometer exercise are shown in Table 4. Maximal oxygen uptake for the three standard modes of exercise correlated highly with that for repetitive lifting, with treadmill demonstrating the strongest relationship. Utilizing treadmill $\dot{V}O_2max$ as the standard, the $\dot{V}O_2max$ for repetitive lifting, arm crank and cycle ergometry are plotted on the ordinate in Figure 2. Power output at repetitive lifting $\dot{V}O_2max$ was not significantly correlated with power output at arm crank or cycle ergometer $\dot{V}O_2max$.

Table 5 lists correlations between variables measured during the repetitive lifting $\dot{V}O_2max$ test and several anthropometric and strength measures. Body mass, fat free mass and maximal machine lift, three variables usually associated with muscle strength, were significantly correlated with absolute repetitive lifting $\dot{V}O_2max$. Power output at repetitive lifting $\dot{V}O_2max$ was significantly correlated with height, percent body fat (negatively), fat free mass and maximal machine lift. Repetitive lifting peak power output was most highly correlated with fat free mass. However, persons with more fat free mass did not tend to lift a heavier box mass during maximal repetitive lifting exercise. Maximal machine lift significantly correlated with repetitive lifting $\dot{V}O_2max$ (r=0.619), but maximal box lift did not. Maximal box lift was significantly correlated with the final box mass lifted during repetitive lifting $\dot{V}O_2max$ test, while the maximal machine lift was not.

Discussion

The repetitive lifting $\dot{V}O_2max$ test was demonstrated to be a reliable measure of aerobic capacity during lifting exercise. Repetitive lifting $\dot{V}O_2max$ correlated highly with the $\dot{V}O_2max$ obtained during the other exercise tests particularly the treadmill test. It is likely that repetitive lifting was more highly correlated with treadmill exercise because both are weight bearing and involve both upper and lower body movement. Inter- and intra-individual differences in skill may be responsible for the lack of correlation between repetitive lifting and arm cranking and leg cycling power output at $\dot{V}O_2max$. Although the $\dot{V}O_2max$ correlated highly among exercise tests, the power output did not. Men who achieved high power outputs on leg cycling or arm cranking did not necessarily reach high power outputs during repetitive lifting. It would be difficult then to predict lifting performance or to set lifting intensity based on a non-lifting $\dot{V}O_2max$ test. A task specific $\dot{V}O_2max$ test is needed to assess lifting ability and describe lifting intensity.

In Figure 1 most individual subjects seem to show a nearly linear increase in $\dot{V}O_2$ with power output during repetitive lifting exercise. Several investigators have either reported or assumed a linear relationship between power output and $\dot{V}O_2$ for repetitive lifting exercise (Intaranont et al. 1986; Miller et al. 1977; Petrofsky and Lind 1978a), and this assumption has been proven accurate at low exercise intensity levels (<50% $\dot{V}O_2max$, Miller et al. 1977). The current data provide an opportunity to examine the linearity of oxygen uptake at higher exercise intensity levels. When submaximal and maximal repetitive lifting power output vs $\dot{V}O_2$ data were plotted with all subjects combined, as shown in Figure 3, the linear relationship was not as strong (r=.65), probably due to the variation in slope and economy between subjects.

Therefore, to determine exercise intensities corresponding to a percentage of lifting $\dot{V}O_2$max, it is necessary to determine each individual's physiological response to repetitive lifting exercise, rather than to assume a standard relationship for all subjects.

In a study of postal package handlers, Peacock (1980) found anthropometric variables, particularly height, to be more important than absolute $\dot{V}O_2$ in successful task performance. In the present study, height was not significantly correlated with repetitive lifting $\dot{V}O_2$max, but was correlated ($p<.05$) with power output during repetitive lifting exercise. It seems logical that a taller person would be able to lift a heavier box mass to 132 cm because of better mechanical advantage. A shorter man must lift a longer vertical distance above waist level than a taller person, thus taxing the shorter man's upper body musculature to a greater extent. For a single lift this relationship appears to hold true, as height was significantly correlated with maximal box lift ($r=.63$). This was not the case for repetitive lifting, however, as height was not significantly correlated with final box mass lifted during the $\dot{V}O_2$max test. The relationship between height and power output during repetitive lifting is probably due to the greater excursion of the center of mass of taller persons during the floor to 132 cm lifting task. A similar relationship seems to hold true for fat free mass and power output ($r=.62$). Fat free mass was not significantly correlated with the final box mass lifted, therefore, persons with more fat free mass achieved higher power outputs without lifting a heavier box mass. These findings lend support to the importance of including the work done to move the body center of mass in the calculation of power output during repetitive lifting exercise.

Table 6 compares the repetitive lifting and cycle ergometer $\dot{V}O_2$max test data from the present experiment with that of Petrofsky and Lind (1978a). The

two groups of subjects appear to have comparable aerobic capacities based on cycle ergometer $\dot{V}O_2max$. Due to greater vertical movement of the body's center of mass, the repetitive lifting $\dot{V}O_2max$ testing procedures used in this study were expected to yield a higher repetitive lifting $\dot{V}O_2max$ than that obtained by Petrofsky and Lind (1978a). Power output in the present experiment was 15-30 watts greater than that of Petrofsky and Lind (1978a) without consideration of the work done to move the body, yet the repetitive lifting $\dot{V}O_2max$ obtained was only slightly higher (Δ=0.19 l•min^{-1}). Based on submaximal repetitive lifting, Intaranont et al. (1986) estimated repetitive lifting $\dot{V}O_2max$ to be 3.16 l•min^{-1} from floor to knuckle height and 2.86 l•min^{-1} from knuckle to shoulder height. Lifting from floor to knuckle height resulted in a higher $\dot{V}O_2max$ than that reported by Petrofsky and Lind (1978a) for lifting to a similar height, and almost equalled the repetitive lifting $\dot{V}O_2max$ of the floor to shoulder height lift in the present study. The floor to knuckle lifting was performed using a squat technique. This requires the lifter to do more work in moving his body than the stoop technique used by most of Petrofsky and Lind's (1978a) and the present experiment's subjects. Regardless of lifting technique, the difference in $\dot{V}O_2max$ between a lift from floor to knuckle height and floor to shoulder height is small. The majority of the energy requirement comes from the floor to knuckle phase of the lift, during which the body weight must also be lifted.

$\dot{V}_E$ at repetitive lifting $\dot{V}O_2max$ was significantly lower than that for maximal treadmill and cycle ergometer exercise, but equal to that at arm cranking $\dot{V}O_2max$. Maximal repetitive lifting $\dot{V}_E/\dot{V}O_2$ was significantly less than that for arm crank and cycle ergometry. This indicates greater utilization of the available oxygen, and might lead to the conclusion that repetitive lifting $\dot{V}O_2max$ is limited by the ability to ventilate the lungs in the stooped over

lifting position. This is not the case, however, as Williams et al. (1982) reported that trunk position during repetitive lifting does not limit maximum breathing capacity. It is interesting to note that during arm crank ergometer exercise in a sitting position, $\dot{V}_E$ at $\dot{V}O_2max$ was equivalent to that for repetitive lifting, but the $\dot{V}O_2max$ was significantly lower. This supports the theory that the quantity of muscle mass involved in exercise is a more important factor in the determination of maximal oxygen uptake than the ability to ventilate the lungs.

Petrofsky and Lind (1978a) report that repetitive lifting exercise at any given box weight had a higher $\dot{V}O_2$ and $\dot{V}E$ than exercise at a comparable cycle ergometer load. They hypothesized that this was due to the energy cost of moving the body parts. The work of moving the body center of mass was included in our calculations, and in most cases, repetitive lifting exercise was still less economical than cycle ergometer exercise. The plots shown in Figure 1 illustrate the relationship of repetitive lifting, cycle ergometer and arm crank ergometer exercise to one another on the power output vs $\dot{V}O_2$ curve. In no instance was cycle ergometer exercise less economical than repetitive lifting or arm crank ergometer exercise. When the data were grouped by exercise type and exercise specific relative intensity, there was a significant difference in economy between all exercise modes at all levels of intensity. Repetitive lifting exercise proved to be less economical than cycle ergometry and more economical than arm cranking. The calculated economy of repetitive lifting exercise might be further increased if the following energy requiring aspects of the lift were corrected for:

1. extra movements involved in the lifting task i.e. pulling the box off the shelf.

2. the brief static effort of holding the box over the shelf and

3. the extra work done in lifting the box higher than shelf level in order to place it upon the shelf.

It appears that the relatively low economy of repetitive lifting is caused by more than the work required to move the body. While the involvement of muscle mass during repetitive lifting exercise is at least as great as that of cycling, a large number of small muscle groups are involved. Many subjects complained of neck, forearm pain and lower back discomfort and fatigue during the course of repetitive lifting exercise. This has also been noted by other investigators studying repetitive lifting (Legg and Pateman 1984; Petrofsky and Lind 1978a, b). Fatigability of small muscle groups may indeed be an important limiting factor in the performance of repetitive lifting exercise and the determination of repetitive lifting $\dot{V}O_2max$. It is likely that the static and stabilizing activity of these small muscles result in decreased blood flow and rapid fatigue.

The NIOSH guidelines (1981) state that persons applying for jobs with high metabolic demands should be tested for aerobic capacity due to the variation in cardiorespiratory fitness in the working population. If the sole objective of performing a $\dot{V}O_2max$ determination was to classify the aerobic capacity of a prospective manual materials handler, any standard exercise capacity test would provide adequate information. A standard $\dot{V}O_2max$ test, however, would not provide information needed to establish the prospective employee's relative exercise intensity while performing a specific lifting task, nor would it provide an indication of that person's lifting skill. In the current study, the mean repetitive lifting $\dot{V}O_2max$ was 78% of the mean treadmill $\dot{V}O_2max$, 89% of the mean leg cycling $\dot{V}O_2max$ and 125% of the mean arm cranking $\dot{V}O_2max$. The average $\dot{V}O_2$ during an 8 hour day is recommended to be no more than 33% $\dot{V}O_2max$ (NIOSH 1981; Snook and Irvine 1968) including short intense lifting

bouts with oxygen uptake requirements of up to 3.0 l•min^{-1}. Based on these recommendations, a healthy young male with a treadmill $\dot{V}O_2$max of 3.50 l•min^{-1} (Vogel et al. 1986) should not have an average $\dot{V}O_2$ exceeding 1.15 l•min^{-1} during an 8 hour day of repetitive lifting. While this represents only 33% of his treadmill $\dot{V}O_2$max, it is 42% of his repetitive lifting $\dot{V}O_2$max, 35% of cycle ergometer $\dot{V}O_2$max and 56% arm cranking $\dot{V}O_2$max. During the short, high intensity exercise bouts required to perform the job, this employee would be exercising at 86% treadmill $\dot{V}O_2$max and a supramaximal load of 110% of his repetitive lifting $\dot{V}O_2$max. These calculations are based on the mean inter test relationship of all subjects combined and does not adequately reflect the large variation between subjects.

Two test subjects may yield identical results on a cycle ergometer $\dot{V}O_2$max test, but have very different oxygen uptakes during identical repetitive lifting tasks due to skill, lifting technique and physiological or morphological differences. In order to accurately assess relative repetitive lifting intensity, the exercise mode selected to measure aerobic capacity must be as close as possible to the lifting task in question, or the relationship between the testing mode and lifting task must be well established for that individual. The repetitive lifting $\dot{V}O_2$max test presented here parallels standard ergometric methods, is a reliable means of assessing aerobic capacity for repetitive lifting and should prove useful as an occupational lifting research tool.

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Table 1. Age, height, body mass, body composition and maximal lifts

(mean and SD, n=18)

	Age (years)	Height (cm)	Body Mass (kg)	Percent Body Fat	Maximal Machine Lift (kg)	Maximal Box Lift (kg)
Mean	23.9	177.7	75.9	15.1	68.8	64.3
SD	3.7	8.9	8.8	4.7	11.3	11.8

Table 2. Physiological responses to repetitive lifting, treadmill, cycle and arm crank ergometer exercise at $\dot{V}O_2max$. Mean ± SD (range).

(n=18)

	$\dot{V}O_2max$ ($l \cdot min^{-1}$)	V_E BTPS ($l \cdot min^{-1}$)	Heart Rate ($beats \cdot min^{-1}$)	$\dot{V}E/\dot{V}O_2$
Repetitive	3.20 ± 0.42	109.9 ± 18.3	181 ± 8.4	34.5 ± 4.5
Lifting	(2.49-3.99)	(71-146)	(168-198)	(26.3-44.5)
Treadmill	4.12 ± 0.53	155.2 ± 29.9	190 ± 9.5	37.1 ± 3.9
Running	(3.10-4.88)	(114-215)	(174-210)	(31.8-43.4)
Cycle	3.63 ± 0.56	144.9 ± 28.9	180 ± 9.8	39.9 ± 5.3
Ergometry	(2.68-4.62)	(96-189)	(160-200)	(30.0-49.6)
Arm Crank	2.57 ± 0.46	114.4 ± 26.9	175 ± 12.7	44.3 ± 5.4
Ergometry	(1.99-3.61)	(84-171)	(149-196)	(35.5-57.9)

Table 3. Economy (watts/l•min^{-1}) of repetitive lifting, arm crank and cycle ergometer exercise at three exercise specific relative intensity levels (Mean ± SD)

Percent peak power output	Repetitive Lifting	Arm Crank Ergometer	Cycle Ergometer
60-74%	59.0 ± 7.0	51.6 ± 4.1	73.3 ± 5.6
75-90%	58.2 ± 9.3	51.9 ± 5.0	77.8 ± 4.2
>90%	60.7 ± 7.9	52.0 ± 5.1	80.5 ± 5.9

Table 4. Correlation of physiological responses to maximal exercise: repetitive lifting vs. treadmill running, arm cranking and leg cycling (n=18)

Repetitive Lifting vs.	Treadmill Running	Arm Cranking	Leg Cycling
$\dot{V}O_2max$ ($l \cdot min^{-1}$)	.908**	.728**	.834**
Heart Rate	.846**	.535*	.688**
$\dot{V}_E$ ($l \cdot min^{-1}$)	.708**	.590**	.590**
$\dot{V}_E/\dot{V}O_2$	.455	.360	.269
Power Output (watts)	NCT	.236	.365
Work (kJ)	NCT	.043	.192

NCT=not calculated for treadmill.

$*p<.05$

$**p<.01$

Table 5. Correlation between repetitive lifting $\dot{V}O_2max$ test variables and selected anthropometric and maximal lift variables.

(n=18)

	Height	Body Mass	Percent Body Fat	Fat Free Mass	Machine Lift[1]	Box Lift[1]
$\dot{V}O_2max$ ($l \cdot min^{-1}$)	.473	.527*	-.156	.622**	.619**	.276
Heart Rate	-.266	-.168	-.291	-.036	.159	-.204
$\dot{V}_E$ ($l \cdot min^{-1}$)	.249	.416	-.275	.557*	.718**	.012
$\dot{V}_E/\dot{V}O_2$	-.228	-.052	-.214	.041	.271	-.360
Final Box Mass	.271	.328	.057	.318	.429	.540*
Power Output	.482*	.333	-.553*	.622**	.596*	.411
Work	.445	.284	-.348	.469	.388	.205

[1] n=17

*p<.05

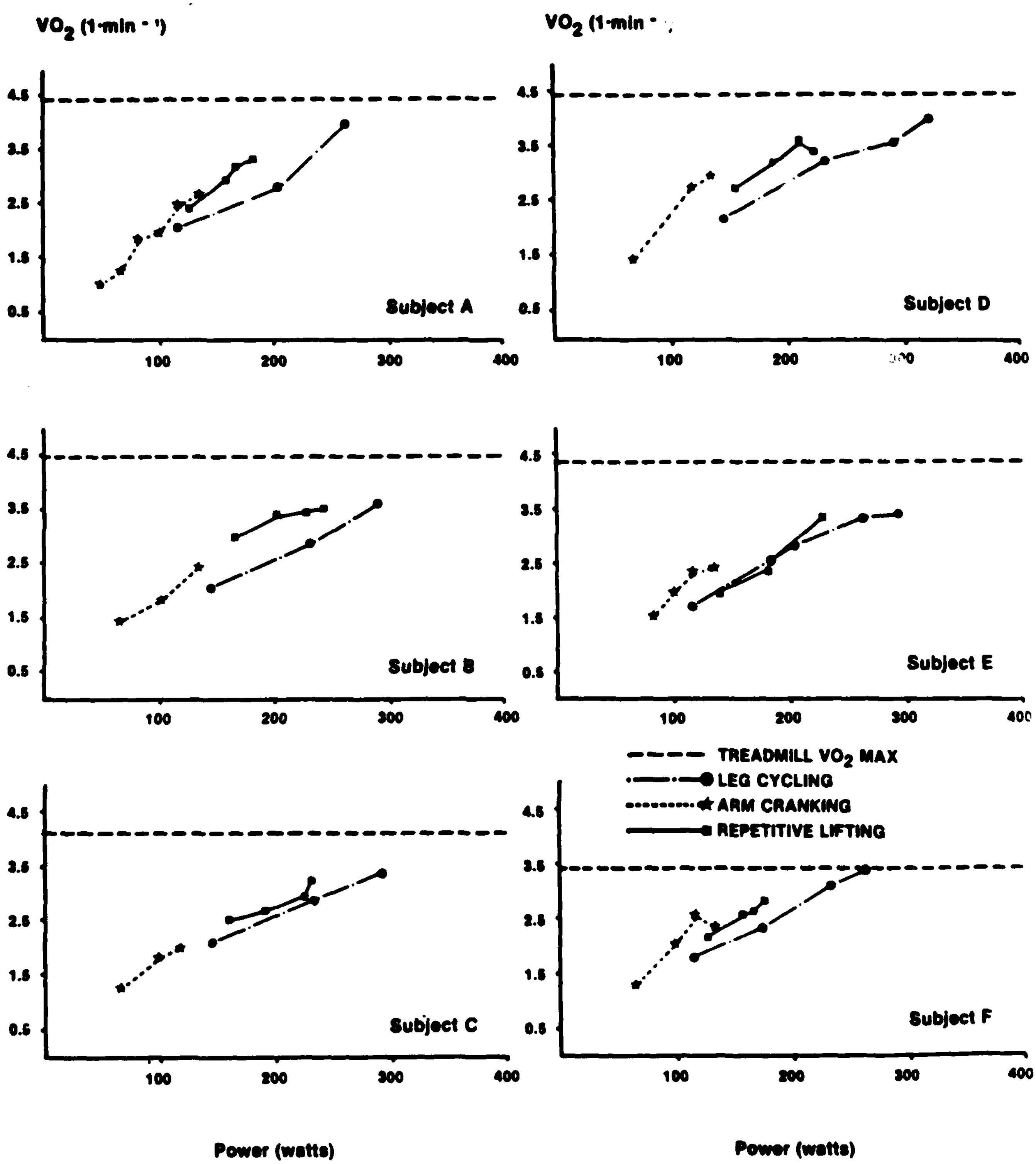
**p<.01

Table 6 Repetitive lifting and Cycle Ergometer $\dot{V}O_2max$ test data from the present experiment and that of Petrofsky and Lind (1978a).

	Cycle Ergometer		Repetitive Lifting	
	Petrofsky and Lind	Present Study	Petrofsky and Lind	Present Study
Box Mass (kg)			36.36	26.3
Power (watts)[1]	250	288	70.6	93.3
Lift Height (cm)			54	132
Rate (rpm) and ($lift \cdot min^{-1}$)	50	60	20-24	15-20
$\dot{V}O_2max$ ($l \cdot min^{-1}$)	3.70 ± 0.38[2]	3.63 ± 0.56	3.01 ± 0.36	3.20 ± 0.42
Heart rate ($bt \cdot min^{-1}$)	187	180	182	181

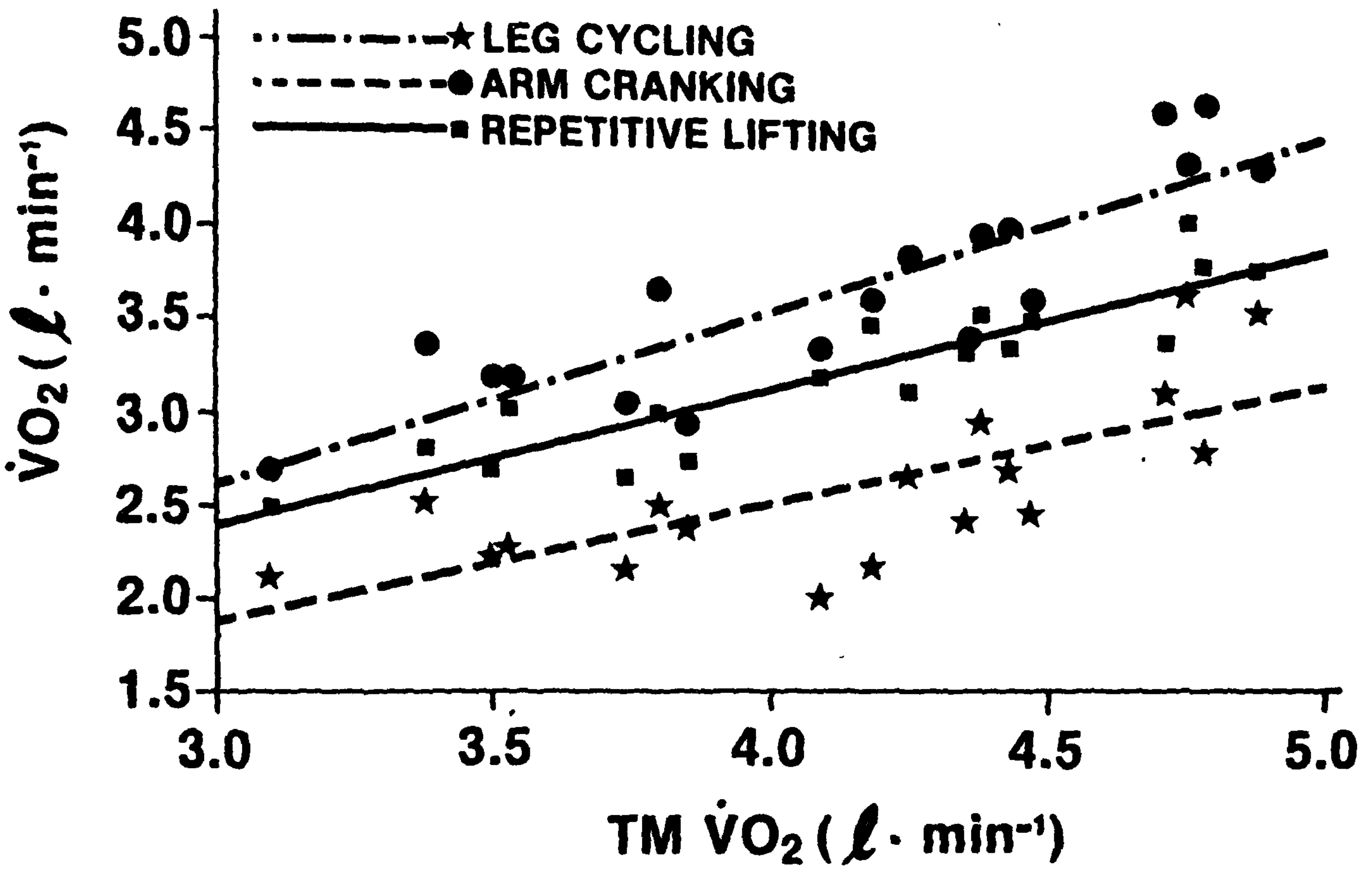
[1]Calculated without consideration of vertical body mass movement.
[2]*Mean ± standard deviation*

Figure 1. Power output vs. $\dot{V}O_2$ for repetitive lifting, leg cycling and arm cranking. Each plot (... F) represents an individual subject. Treadmill $\dot{V}O_2max$ is indicated as a horizontal dashed line.



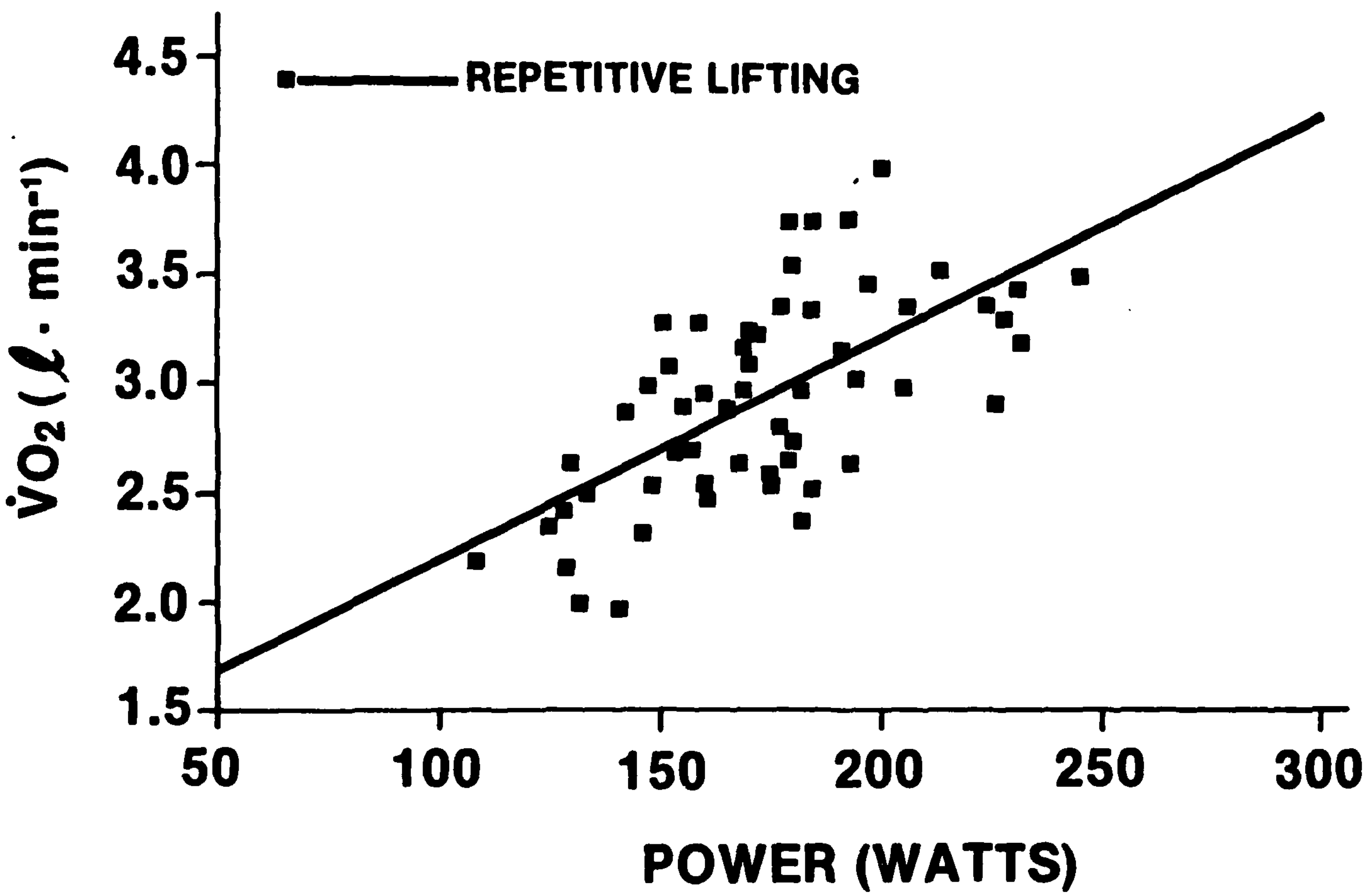
VO2 (1·min⁻¹)
Subject A
Subject D
Subject B
Subject E
Subject C
Subject F
TREADMILL VO2 MAX
LEG CYCLING
ARM CRANKING
REPETITIVE LIFTING
Power (watts)

Figure 2. $\dot{V}O_2max$ during repetitive lifting, leg cycling and arm cranking vs. $\dot{V}O_2max$ during treadmill running (n=18).



LEG CYCLING
ARM CRANKING
REPETITIVE LIFTING
$\dot{V}O_2$ ($\ell \cdot min^{-1}$)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
3.0
3.5
4.0
4.5
5.0
TM $\dot{V}O_2$ ($\ell \cdot min^{-1}$)

Figure 3. $\dot{V}O_2$ ($l \bullet min^{-1}$) vs. power output (W) during submaximal and maximal repetitive lifting exercise (n=18).


REPETITIVE LIFTING
$\dot{V}O_2$ ($\ell \cdot min^{-1}$)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
50
100
150
200
250
300
POWER (WATTS)